GENESIS OF SOLONETZIC SOILS IN RELATION TO HYDROGEOLOGY IN THE HANLEY AND CENTRAL BUTTE AREAS OF SASKATCHEWAN

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INTRODUCTION

In Saskatchewan there are approximately 1.5 million hectares of dominant Solonetzic soil, often found in association with normal or Chernozemic soils (Anderson and Ballantyne, 1982). Solonetzic soils are widely distributed in all major soil zones (Janzen and Moss, 1956) but largely occur in the Brown and the Dark Brown soil zones (Mitchell et al., 1944).

Solonetzic soils are characterized by a thin layer of topsoil, or A horizon, underlain by a massive, columnar, structured B horizon, which in turn is underlain by a lime-salt layer, or C horizon (Cairns and Bowser, 1977). Primarily due to a hard compact B horizon and a high subsoil salt content, solonetzic soils create special management problems for farmers.

Reclamation techniques have been aimed at increasing crop production levels. Techniques such as deep plowing, the addition of gypsum and the application of commercial products have yielded variable to ineffective responses (Toogood and Cairns, 1978).

Previous literature suggests that solonetzic soils may evolve from either present groundwater conditions, past groundwater conditions or saline parent materials. Many workers found solonetzic soils in areas of groundwater discharge and believed that sodium was transported by groundwater to points within the soil pedon (Kellogg, 1934, Westin, 1953, Pratt and Ellis, 1954, Redmond and McClelland, 1959, Kovada, 1965, Szabolcs, 1965, Varallyay, 1968, Arshad and Pawluk, 1975, Buylov, 1976, Pawluk, 1982). Such solonetzic soils were generally refered to as hydromorphic.

Other researchers believed that solonetzic soils were developed in the advent of a past saline water table (Whittig, 1959, Matzek, 1955, Kovda, 1965, Maclean and Pawluk, 1975, Kisel, 1981). Solonetzic columnar macrostructures were described as "relict" or "residual" and were found overlying areas where groundwater discharge was no longer present. Several authors refered to such solonetzic soils as paleohydromorphic.

Many solonetzic soils in areas of the north-central United States, the U.S.S.R., and the prairie provinces of Western Canada were reported to have developed from originally saline (often marine) parent material in the absence of a water table or capillary fringe (Joel, 1933, Kelley 1934, White and Papendick, 1961, White, 1964, Reeder and Odynsky, 1964, Polupan et al., 1979, Tyul'panov,1980, Kisel,1981, Parakshin, 1982, Munn and Boehm, 1983). Such solonetzic soils were often refered to as lithosolic or lithogenic. In this paper they will be refered to as lithogenic.

By previously defining pertinent factors that contribute to or have contributed to the accumulation of sodium within the pedon, effective management and/or reclamation procedures could then be considered. The objective of this paper is to document hydrogeologic conditions in the Hanley and Central Butte solonetzic areas.

INVESTIGATIVE METHODS

Pedological information for the Hanley and Central Butte areas was obtained from the "Soils of the Rosetown Map Area" and the "Soils of the Swift Current Map Area", respectively. Both soil maps were published by the Saskatchewan Institute of Pedology. Solonetzic soils in both areas were subdivided into dominant Solonetzic, dominant Solodic, significant

Solonetzic, and significant Solodic groups (not shown in this paper).

Dominant Solonetzic groups included all map units with dominant Solonetz and/or dominant Solodized Solonetz series while dominant Solodic groups included all map units with dominant Solod series. Significant Solonetzic and significant Solodic groups consisted of map complexes. Map complexes consisted of two or more map units in which the first map unit represented the dominant soil type while the second map unit represented the significant soil type in any one area.

Significant Solonetzic groups usually consisted of a dominant nonsolonetzic map unit combined with a significant solonetzic map unit which possessed either a dominant Solonetz or a dominant Solodized Solonetz series. Similarily, significant Solodic groups consisted of a dominant nonsolonetzic map unit combined with a significant solonetzic map unit which possessed a dominant solod series.

Elevations were determined from 1:250,000 scale topographic maps obtained from the Department of Energy, Mines, and Resources (1977).

Geologic data was largely derived from Geology and Groundwater Resources Maps obtained from the Saskatchewan Research Council. Additional information was obtained from private and public geological reports and Ph.D. and M.Sc. theses obtained from the Department of Geology, University of Saskatchewan.

Groundwater chemistry information was largely obtained from the Saskatchewan Research Council report entitled "Water Quality Survey of Saskatchewan Groundwaters" (Rutherford, 1967). Additional information was obtained from the "Geological Survey of Canada Water Supply Papers" and the Geology and Groundwater Resources Maps.

Water well data was largely obtained from the Geological Survey of Canada Water Supply Papers (1936) and the Saskatchewan Environment

(1985) records. Water wells with static pressure heads within 10 feet (3.0 m) of ground surface were plotted independently from water wells with pressure heads at and above ground surface. A maximum depth of 10 feet (3.0 m) below ground surface was selected on the basis of existing literature. This literature indicated that sodic, saline, and solonetz soils generally occurred where saline water tables were between 0.5 and 3.0 meters below ground surface (Szabolcs, 1965 and 1978, Varallyay, 1968, Maclean and Pawluk, 1975, Buylov, 1976).

Specific water well information was obtained from well logs and water well completion records. Water well completion records indicated the type of geologic sediment in which the water well was completed (glacial or bedrock). Water wells completed in glacial drift were plotted independently from wells completed in bedrock sediments. In many cases records were incomplete and data was not available.

Most water wells were drilled prior to the use of electric logging equipment. In many cases, the identification of bedrock formations was based on the personal interpretation of water well driller. Many bedrock aquifers at that time were interpreted and recorded as belonging to the Judith River Formation.

Types of solonetzic soils in local and regional landscapes, characteristics of soil parent materials, chemistry of bedrock waters, and pressure heads in bedrock aquifers were studied and a "most probable" theory of sodium accumulation in solonetzic soils was formulated. Due to the complex nature of the figures for each study area the author was not able to include all of them with the proceedings. For reference to all the figures please refer to: Luba,L.D. unpublished M.Sc. thesis (1987). Genesis of Solonetzic soils in relation to hydrogeology in southern Saskatchewan, Department of Soil Science, University of Saskatchewan, Saskatoon.

RESULTS AND DISCUSSION

a) Hanley study area

The Hanley study area includes townships 24 to 31, ranges 2 to 7, west of the third meridian (Figure 1). The Allan Hills Upland occupies areas in the northeast while the Hawarden Hills Upland occupies an area in the west central portion of the study area. The Saskatchewan Rivers Plain encompasses the Hawarden Hills and areas southwest of the Allan Hills Upland (Figure 1).

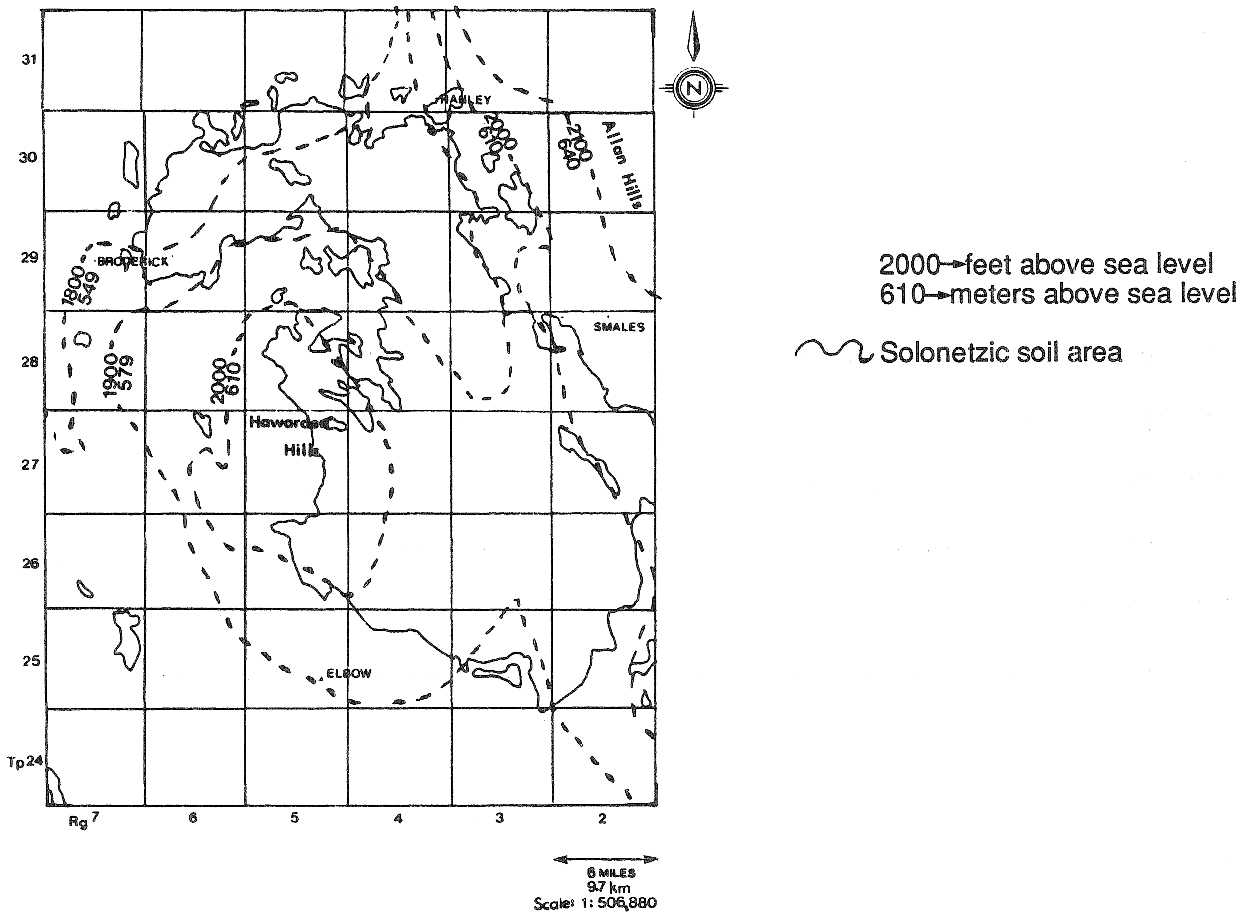


Figure 1. Elevations and solonetzic soil areas in the Hanley study area redrawn after the Department of Energy, Mines and Resources (1977) and Ellis et al. (1968), respectively.

Between the Allan Hills and Hawarden Hills Uplands, glacial drift is between 0 and 50 feet (0 and 15 m) thick. Glacial drift is greater than 200 feet (61 m) thick in the Allan Hills and Hawarden Hills Uplands (Harder and Henry, 1986).

The Upper Cretaceous Bearpaw Formation forms the bedrock surface in most of the Hanley study area (Christiansen and Meneley, 1971). It is from 0 to 950 feet (0 to 290 m) thick and consists of gray, noncalcareous silt and clay (Christiansen and Meneley, 1971) with several extensive sandy beds (Caldwell, 1968).

The Judith River Formation underlies the Bearpaw Formation and is between 0 and 200 feet (0 and 61 m) thick (Christiansen and Meneley, 1971). The formation is composed of noncalcareous mixed beds of sand, silt, and clay, with some beds of coal and concretions (McLean, 1971).

Water from 23 wells completed in the Bearpaw Formation was of a sodium sulfate type with an average sodium adsorption ratio (SAR) of 39.4 (Rutherford, 1967). Water from the Bearpaw Formation was poorly suited for irrigation due to very high levels of soluble salts and sodium (Richards, 1954 and Rutherford, 1967).

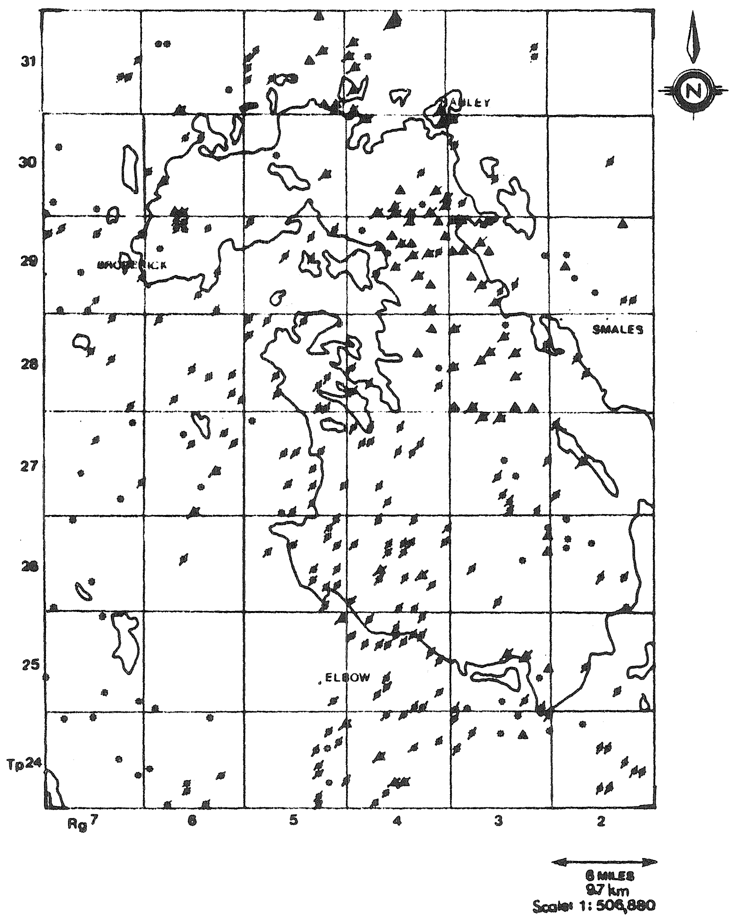
Water from 30 wells completed in the Judith River Formation was of a sodium sulfate, chloride and bicarbonate type with an average SAR of 63.0 (Rutherford, 1967). Water was also poorly suited for irrigation due to very high levels of soluble salts and sodium (Richards, 1954 and Rutherford, 1967).

More than 60 water wells completed in bedrock aquifers with pressure heads near and above ground surface occur in the Hanley study area (Figures 2 and 3). Over fifty of the water wells occur in dominant Solonetzic areas, four in dominant Solodic areas, one in a significant Solonetzic area, and none in significant Solodic areas (not shown in this paper).

Dominant Solonetzic Soils

Dominant solonetzic soils largely occur in the Saskatchewan Rivers Plain between the Hawarden Hills and the Allan Hills Uplands. Hanley, Rosemae, and Tuxford soils occupy the largest areas in the dominant Solonetzic group.

Hanley, Rosemae, and Tuxford soils occur on gently to very gently undulating topography and parent materials are moderately saline and calcareous. Solonetz series generally occur on upper slopes or knolls, Solodized Solonetz series on mid slopes and Solod series on lower slopes above poorly drained depressional areas (Ellis et al., 1968).



Static pressure head within 10 feet (3.0 m) of ground surface (Geological Survey of Canada, 1936).

Static pressure head within 10 feet (3.0 m) of ground surface (Saskatchewan Environment, 1985).

Pressure head at and above ground surface (Geological Survey of Canada,1936).

Pressure head at and above ground surface (Saskatchewan Environment, 1985).

Figure 2. Location of water wells with pressure heads at and above ground surface and static pressure heads within 10 feet (3.0 m) of ground surface.

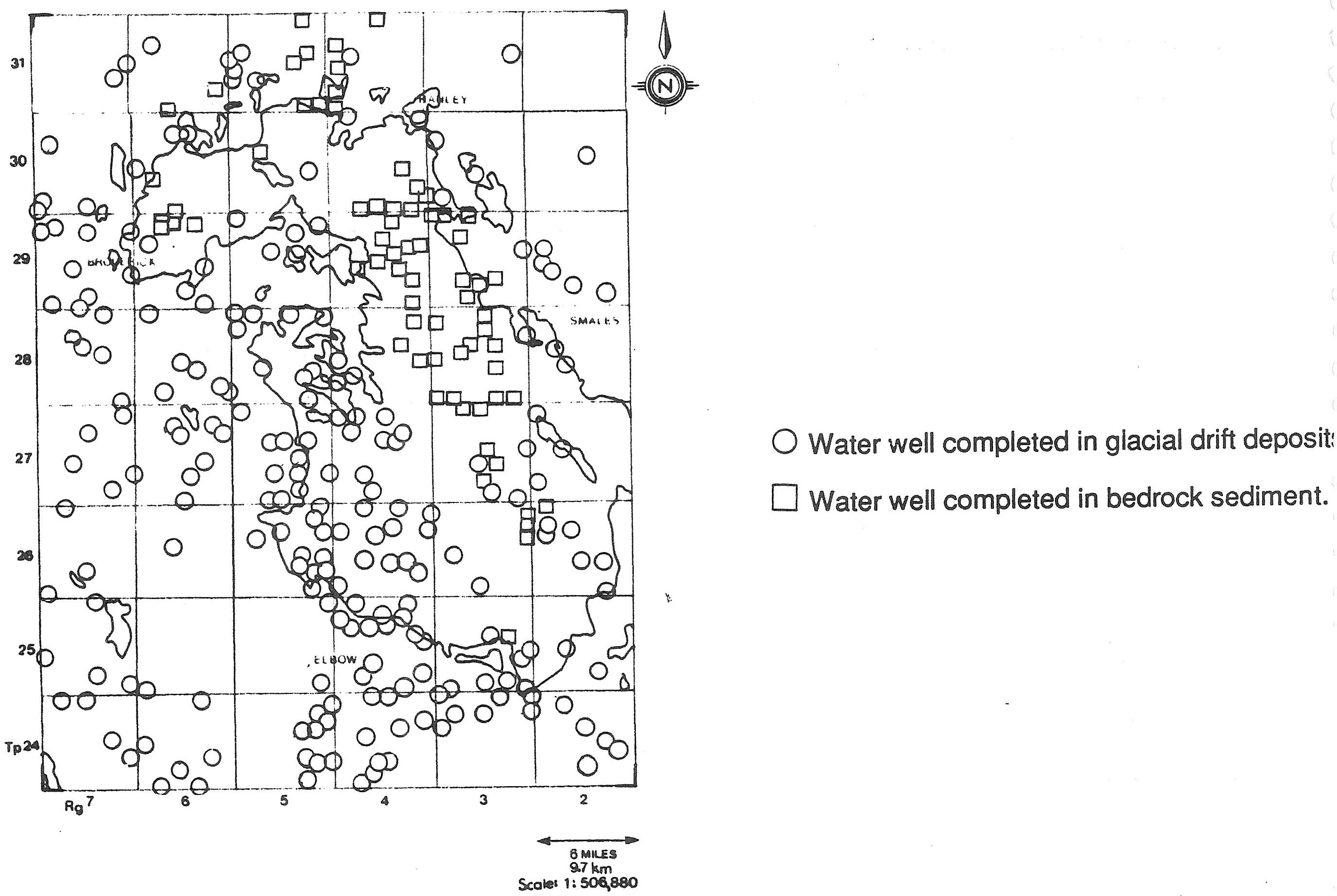


Figure 3. Location of water wells that are completed in glacial drift deposits and those that are completed in bedrock sediments.

Dominant Solonetzic soils in regionally low landscapes, an absence of Upper Cretaceous shales in moderately saline parent materials, very high sodium salt levels in waters from bedrock aquifers, and high pressure heads in bedrock aquifers suggest that hydromorphic processes of sodium accumulation occur in dominant Solonetzic areas.

<u>Dominant Solodic Soils</u>

Dominant Solodic soils largely occur along the western edge of the Allan Hills Upland and the northern edge of the Hawarden Hills Upland. Rosemae and Hanley soils the occupy largest areas in the dominant Solodic group. Parent materials of Rosemae and Hanley soils are moderately saline and calcareous. Solod series generally occur on lower slopes above poorly drained depressional areas, while Solonetz series occupy upper areas or knolls (Ellis et al., 1968).

An absence of Upper Cretaceous shales in moderately saline parent materials, solod profiles in lower slopes of the local landscape, very high sodium salt levels in waters from bedrock aquifers, and high pressure heads in bedrock aquifers suggest that hydromorphic processes of sodium accumulation occur in dominant Solodic areas. Water wells completed in bedrock aquifers with pressure heads near and above ground surface are assumed to occur in poorly drained depressional areas below solod profiles.

Pawluk (1982) explained that three classic soil forming processes; salinization, solonization, and solodization formulated an adequate basis for a step-wise presentation of the mechanisms responsible for the generation of solonetzic soils. Pawluk (1982) theorized that it was first necessary to concentrate and maintain a dominance of sodium salts at the surface or within the upper section of the pedon by groundwater discharge. While salinization preceeded the evolution of solonetz soils, certain conditions are required before solonization can occur; (1) salt accumulations in the saline soil must contain a significant amount of sodium ions, (2) the clay mineral suite required a significant component of expandable constituents, and (3) there must be a net adjustment in environment conditions favouring gradual desalinization (Pawluk, 1982).

Desalinization, solonization, and finally solodization probably occurred in dominant Solodic soils as a result of falling pressure heads and may represent a stepwise transformation from past Solonetzic profiles to present day Solodic profiles. High pressure heads in bedrock aquifers, presumably in depressional areas, indicate that sodium accumulation in dominant Solodic soils, were at a past time, related to hydromorphic processes. Present day dominant solod profiles may be related to paleohydromorphic processes of sodium accumulation.

Significant Solonetzic and significant Solodic soils

Significant Solonetzic and significant Solodic soils occupy eastern portions of the Hawarden Hills and southwestern portions of the Allan Hills Uplands. Weyburn-Rosemae soils occupy largest areas in the significant Solonetzic and the significant Solodic groups. Orthic Weyburn soils occupy knolls and upper slopes while Solonetzic and Solodic Rosemae soils occupy remaining portions in the landscape (Ellis et al., 1968). Weyburn parent material consists of nonsaline, unsorted glacial till while Rosemae parent materials consist of moderately saline, unsorted glacial till (Ellis et al., 1968). Pressure heads in bedrock aquifers are generally between 20 and 150 feet (6.1 and 46 m) below ground surface.

An absence of Upper Cretaceous shales in soil parent materials, solonetzic soils with moderately saline parent materials confined to lower portions of the local landscape, and low pressure heads in bedrock aquifers, suggest that the accumulation of sodium in solonetzic soils may be related to paleohydromorphic processes.

Essential elements enhancing salinization were much more profound during the earlier part of the Holocene (Pawluk, 1982). If pressure heads in bedrock aquifers were greater at a past time particularily during immediate post glacial times (Mumm and Boehm, 1983). Present day Solodic profiles may have previously been Solonetz and/or Solodized Solonetz profiles. Morrison and Frye (1965) postulated that a wet post-glacial climatic period ended about 4000 years B.P. and semi-arid conditions became prevalent (after Munn and Boehm, 1983).

If semi-arid conditions became prevalent, recharge into bedrock aquifers would have presumably decreased and pressure heads in bedrock aquifers would have continuously fallen. Accompanying falling pressure heads, previously saline soils may have undergone desalinization, solonization and finally solodization. A saline profile may have transformed into a Solonetz profile followed by a Solodized Solonetz profile and later a Solod profile.

b) The Central Butte Study Area

The Central Butte study area includes townships 17 to 23, ranges 28 and 29, west of the second meridian and ranges 1 to 7, west of the third meridian (Figure 4). The Assiniboine River Plain and the Eyebrow Hills Upland occur in the northeast half while the Missouri Coteau Upland (Vermilion Hills) occurs the southwest half of the study area (Figure 4). The Central Butte Plain forms one subsection in the Assiniboine River Plain and occupies areas west and south of the Eyebrow Hills Upland and the Missouri Coteau Upland (Vermilion Hills), respectively.

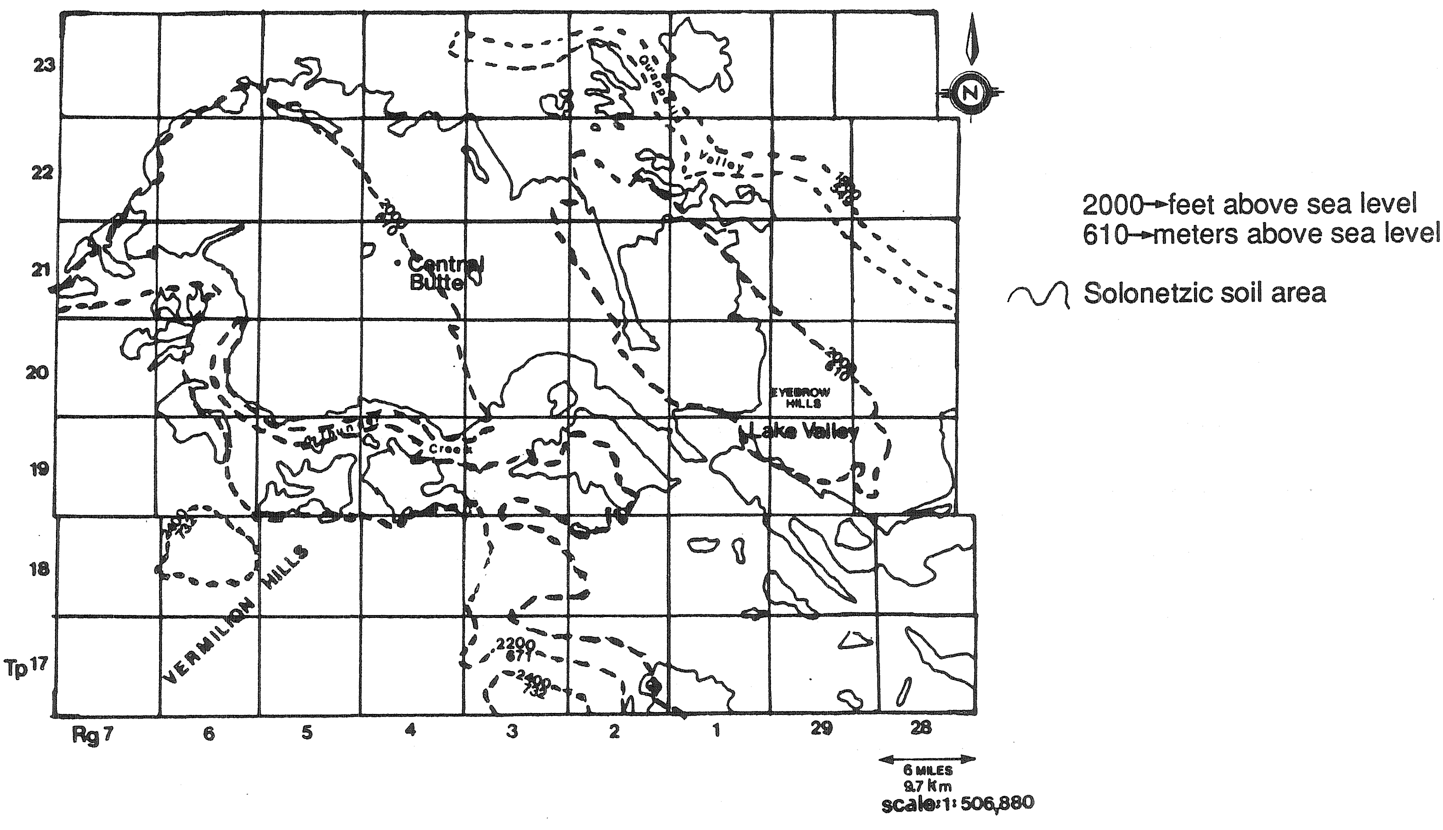


Figure 4. Elevations and solonetzic soil areas in the Central Butte study area redrawn after the Department of Energy, Mines and Resources (1977) and Ayers et al. (1985), respectively.

Glacial drift varies in thickness from about 600 feet (183 m) in the Missouri Coteau Upland, to about 100 feet (30 m) in the Central Butte Plain, and about 50 feet (15 m) in the Eyebrow Hills Upland (Whitaker, 1970).

The Bearpaw Formation forms the bedrock surface in most of the study area. It is from 350 to 1200 feet (100 to 366 m) thick and consists of gray, noncalcareous, silty clay and clay. It is locally bentonitic and concretionary and includes several sandy shale zones and sand members of large areal extent (Whitaker, 1970).

The Judith River Formation underlies the Bearpaw Formtion and is between 100 to 250 feet (30 and 76 m) thick (Whitaker, 1970). It consists of interbedded gray colored, sand, silt, and clay. It is commonly carbonaceous, noncalcareous, and locally bentonitic and concretionary (Whitaker, 1970).

Water from 26 wells completed in the Bearpaw Formation was of sodium sulfate, bicarbonate, chloride types with an average sodium adsorption ratio of 33.1 (Rutherford, 1967). Water was poorly suited for irrigation due to medium and very high levels of sodium and high to very high levels of soluble salts (Richards, 1954 and Rutherford, 1967).

Water from 4 wells completed in the Belly River (Judith River) Formation was of sodium bicarbonate and chloride types with an average sodium adsorption ratio of 49.7 (Rutherford, 1967). Water was poorly suited for irrigation due to very high levels of sodium and high levels of soluble salts (Richards, 1954 and Rutherford, 1967).

In 1931, Maddox and Wickenden approximated the limits of the Central Butte artesian area. The northern limit was defined at the northern margin of township 22, the eastern boundary at the eastern limit of range 3, the southern boundary at the northern limit of township 19, and the western boundary at the western limit of range 7 (Maddox, 1932).

In an attempt to locate the recharge area, Maddox (1932) excluded areas to the north, east, and south due to unfavorable surface elevations and insignificant rises in water level. Maddox (1932) concluded that areas to the west and southwest provided the most favourable areas for groundwater recharge. The Swift Current Creek was established as a possible recharge source.

More than 50 water wells in the Central Butte study area were completed in bedrock aquifers and had pressure heads near and above ground surface (Figures 5 and 6). Thirty four of the water wells occur in dominant Solonetzic areas, one in a dominant Solodic area, fourteen in significant Solonetzic areas, and seven in significant Solodic areas (not shown in this paper).

Dominant Solonetzic Soils

Dominant Solonetzic soils occur throughout most of the Central Butte Plain. Together Echo and Kettlehut soils occupy the largest areas in the dominant Solonetzic group. Echo and Kettlehut soils occur on gently sloping to gently and roughly undulating topography. Parent materials consist of moderately calcareous, saline modified glacial till dominated by local residual Cretaceous shales (Ayers et al., 1985). Surface soil textures range from loam to clay loam to clay (Ayers et al., 1985).

Solonetz series usually occur on higher elevations above Solodized Solonetz series. Solod series usually occur on lower slopes. More than 50 local Saline Regosol soil areas occur in a scattered pattern throughout southern, eastern, and northern portions of the Central Butte Plain. Only a few Saline Regosol soil areas occur in western portions of the Central Butte Plain. Saline Regosol soils occupy poorly drained depressional areas in the local landscape (Ayers et al., 1985).

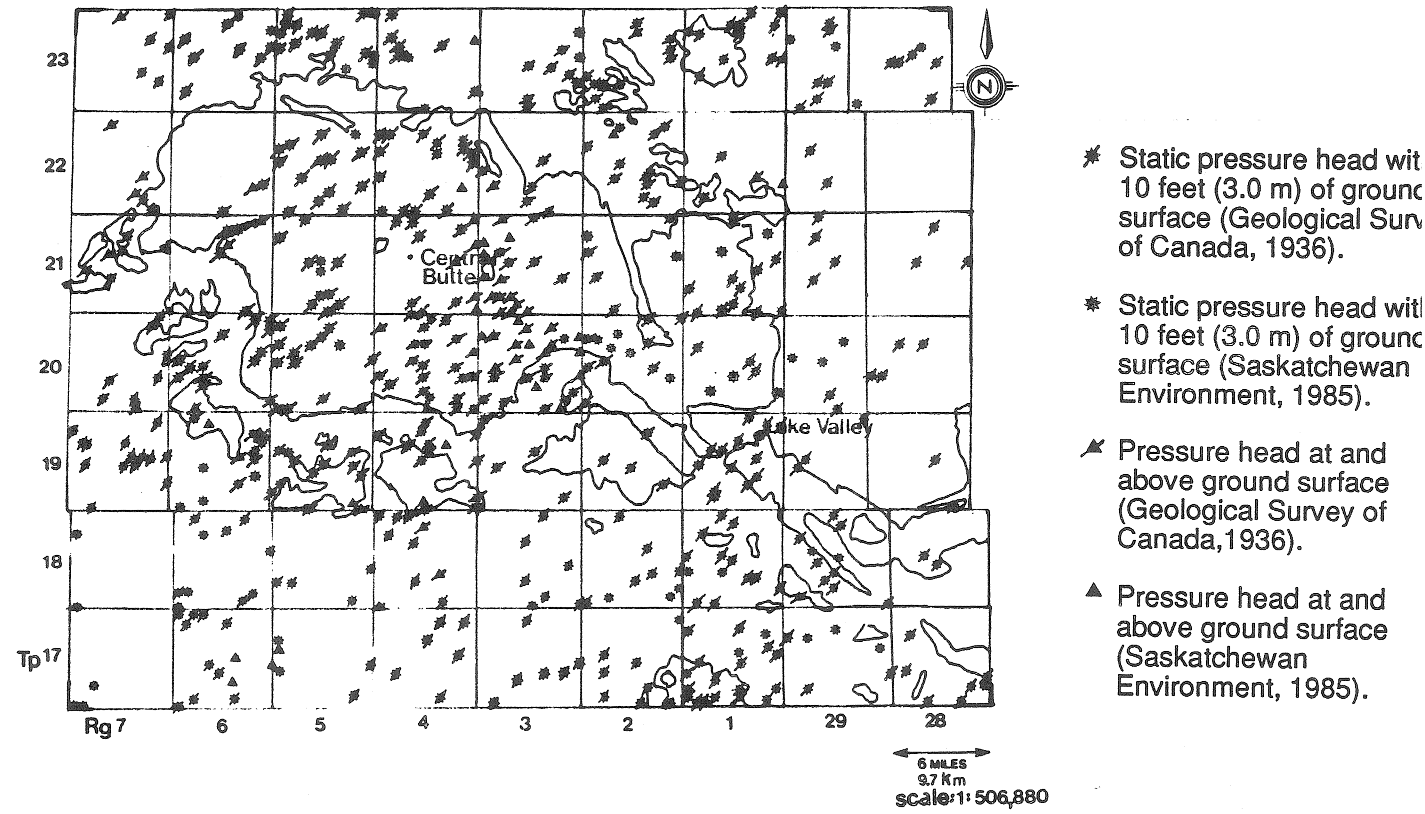


Figure 5. Location of water wells with pressure heads at and above ground surface and static pressure heads within 10 feet (3.0 m) of ground surface.

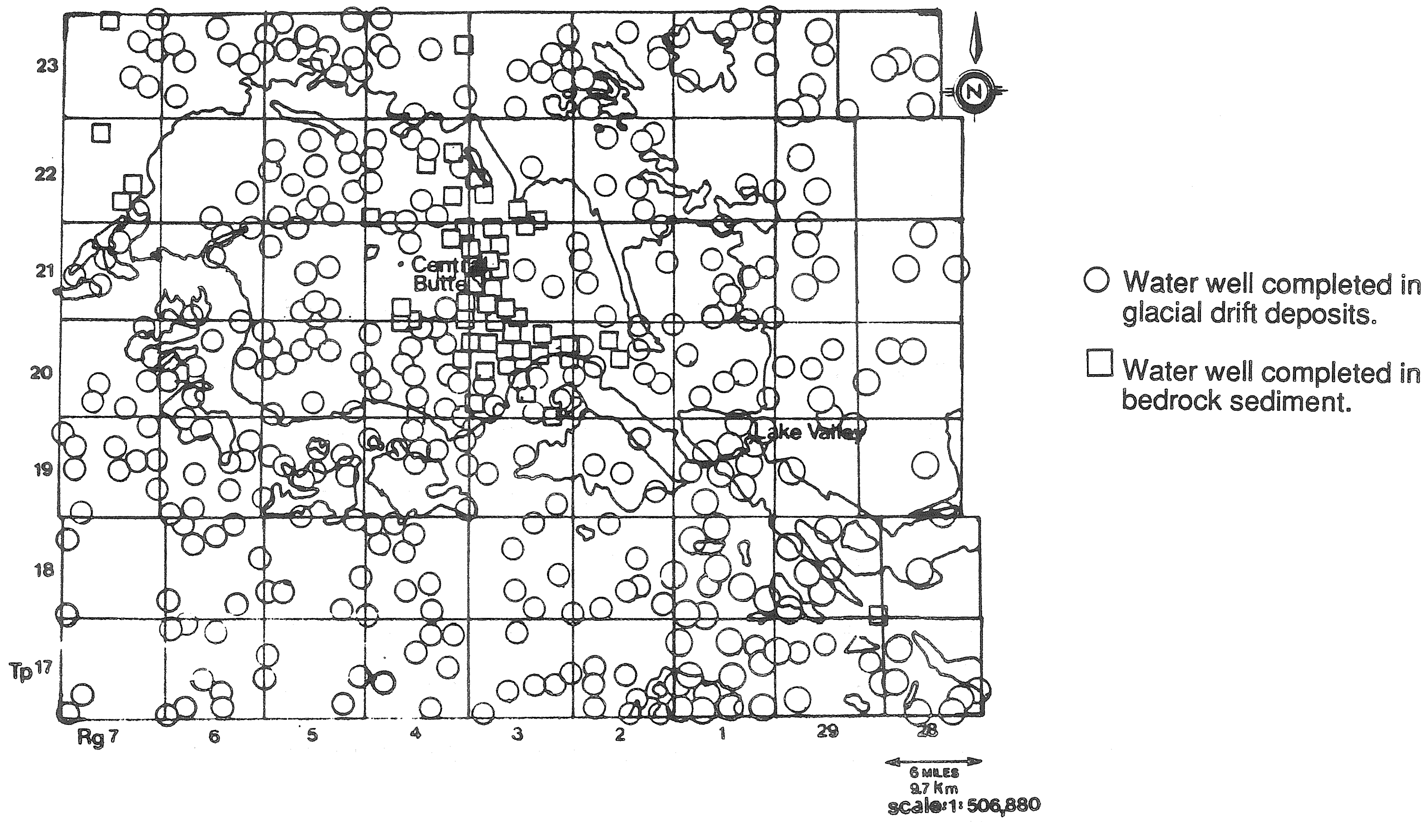


Figure 6. Location of water wells that are completed in glacial drift deposits and those that are completed in bedrock sediments.

Initial evidence of glacial till parent material dominated by local residual Cretaceous shales suggest that lithogenic processes may be contributing to sodium accumulation in Echo and Kettlehut soils. Further evidence of medium to very high levels of sodium salt in bedrock waters and pressure heads near and above ground surface in eastern portions of the Central Butte Plain suggest that hydromorphic processes may also be contributing to sodium accumulation in Echo and Kettlehut soils.

The location of many depressional Saline Regosolic soils in eastern portions of the the Central Butte Plain correlate well with areas of high pressure head in bedrock aquifers. Depressional Saline Regosolic soils may be indicative of groundwater discharge from bedrock aquifers.

In western portions of the Central Butte Plain, there are no water wells completed in bedrock aquifers that have pressure heads within 10 feet (3.0 m) of ground surface. However, several depressional Saline Regosolic soil areas occur in the area and may indicate conditions of groundwater discharge and perhaps sodium accumulation in solonetzic soils.

Dominant Solodic Soils

Several small dominant Solodic areas occur adjacent to dominant Solonetzic soils in the Central Butte Plain. Gilroy soils occupy the largest areas in the dominant Solodic group and occur on gently sloping to gently and roughly undulating topography. Solod series usually occupy lower slopes below Solodized Solonetz series in local landscapes. Parent materials consist of moderately calcareous, weakly to moderately saline, sandy glacio-lacustrine deposits containing over 15% clay (Ayers et al., 1985). There are no water wells completed in bedrock aquifers that have pressure heads within 10 feet (3.0 m) of ground surface. However, neighbouring water wells have pressure heads near and above ground surface.

Evidence of saline parent materials, an absence of Upper Cretaceous shales in parent materials, solod profiles in lower slopes, and neigbouring water wells with pressure heads near and above ground surface suggest that sodium accumulation in dominant Solodic soils may be related to paleohydromorphic processes.

Hydrophysical properties of coarse textured Gilroy soils likely favour greater hydraulic conductivities than fine textured soils. Seasonal precipitation and runoff may percolate light textured Gilroy soils providing greater downward fluxes of sodium salt than upward fluxes originating from bedrock aquifers.

Pawluk (1982) suggested that there must be a net adjustment in environment conditions favouring gradual desalinization before solonization and solodization occur. Desalinization, solonization, and finally solodization probably occurred as a result of falling pressure heads and may represent a stepwise transformation from past Solonetz and Solodized Solonetz profiles to present day Solod profiles.

Significant Solonetzic Soils

Significant Solonetzic soils occur in northern portions of the Missouri Coteau, in portions of the Eyebrow Hills, and encompasses nearly all dominant Solonetzic soils in the Central Butte Plain. Ardill-Kettlehut, Weyburn-Rosemae, and Sutherland-Tuxford soils occupy the largest areas in the significant Solonetzic group.

Several groups of scattered Ardill-Kettlehut soils occur in northern portions of the Missouri Coteau Upland. These soils occur on moderately sloping to gently rolling topography. A second group of Ardill-Kettlehut soils occur in southern portions of the Central Butte Plain. These soils largely occur on gently sloping to gently and roughly undulating topography (Ayers et al., 1985).

Ardill-Kettlehut parent materials consist of Cretaceous shale-modified glacial till (Ayers et al., 1985). Ardill parent materials are moderately calcareous and nonsaline while Kettlehut parent materials are moderately calcareous and saline. In local landscapes, Ardill soils occupy upper slopes while Kettlehut soils commonly occur in lower slopes (Ayers et al., 1985). Several depressional Saline Regosolic soils occur in areas dominated by Ardill-Kettlehut soils. There are no water wells, completed in bedrock aquifers, that have pressure heads near or above ground surface.

Initial evidence of Cretaceous shale-modified glacial till in Ardill-Kettlehut parent materials and low pressure heads in bedrock aquifers suggest that lithogenic processes of sodium accumulation may be dominant. Similar to solonetzic Ardill-Kettlehut soils, adjacent nonsolonetzic Ardill soils are developed on identical landscapes from similar parent materials. This would suggest that lithogenic processes of sodium accumulation are not dominant in Ardill-Kettlehut soils.

Evidence of moderately saline Kettlehut parent materials confined to lower positions in the local landscape and several depressional Saline Regosolic soils mapped in Ardill-Kettlehut areas suggest that sodium accumulation in Ardill-Kettlehut soils may be related to hydromorphic processes.

Significant Solonetzic Weyburn-Rosemae soils largely occur in central portions of the Eyebrow Hills and eastern portions of the Central Butte Plain. Soils occur on gently sloping to gently and roughly undulating topography. Weyburn parent materials consist of nonsaline glacial till while Rosemae parent materials consist of moderately to strongly saline glacial till. Weyburn soils occur on upper slopes and Rosemae soils on mid and lower slopes (Ayers et al., 1985). Fourteen water wells completed in bedrock aquifers have pressure heads near and above ground surface and water wells are mostly confined to eastern portions of the Central Butte Plain.

An absence of Cretaceous shales in Weyburn and Rosemae parent materials, moderately to strongly saline parent materials confined to lower slopes, medium to very high sodium salt levels in waters from bedrock aquifers, and high pressure heads in water wells completed in bedrock aquifers suggest that hydromorphic processes of sodium accumulation are dominant in Weyburn-Rosemae areas within eastern portions of the Central Butte Plain.

Weyburn-Rosemae soils in the Eyebrow Hills occur under similar conditions except there are no water wells completed in bedrock aquifers that have pressure heads within 10 feet (3.0 m) of ground surface. An absence of Cretaceous shales in soil parent materials and moderately to strongly saline parent materials in lower slopes suggest that past hydrologic conditions probably favoured greater pressure heads particularily in bedrock aquifers. Rosemae solonetzic soils in lower slope positions may have become salinized with abundant sodium salts. As pressure heads fell with warmer and drier climatic conditions, desalinzation followed by solonization may have occurred resulting in present day Rosemae solonetzic soils in lower slopes. Sodium accumulaiton in significant Solonetzic soils in the Eyebrow Hills are probably related to paleohydromorphic processes.

Significant Solonetzic Sutherland-Tuxford soils occur in southern portions of the Eyebrow Hills and in areas immediately south of the Eyebrow Hills. Soils largely occur on very gently sloping to very gently undulating topography. Both Sutherland and Tuxford parent materials consist of variable clayey glacio-lacustrine deposits except Sutherland parent materials are moderately calcareous and nonsaline and Tuxford parent materials are moderately calcareous and saline. Sutherland soils occur on upper slopes while Tuxford soils occupy mid and lower slopes (Ayers et al., 1985). There are no water wells completed in bedrock aquifers that have pressure heads within 10 feet (3.0 m) of ground surface.

An absence of Cretaceous shales in the soil parent materials, moderately saline parent materials confined in lower slopes, and low pressure heads in bedrock aquifers suggest that sodium accumulation may be related to conditions when pressure heads in bedrock aquifers were greater than presently indicated. Sodium accumulation in Significant Solonetzic soils in southern portions of the Eyebrow Hills may be related to paleohydromorphic processes.

Significant Solodic Soils

Significant Solodic soils largely occur in the Eyebrow Hills and in areas along the eastern edge of the Central Butte Plain. Amulet- Brooking, Weyburn-Hanley and Weyburn-Rosemae soils occupy the largest areas in the significant Solodic group.

Amulet-Brooking soils largely occur in the Eyebrow Hills on gently sloping to gently and roughly undulating topography. Amulet and Brooking soils are both developed from glacial till modified by Upper Cretaceous clay-shale (Ayers et al., 1985). However, Amulet parent materials are nonsaline while Brooking parent materials are moderately calcareous and saline. In local landscapes, Amulet soils occur in upper slopes and Brooking soils in lower slopes (Ayers et al., 1985). There are no water wells completed in bedrock aquifers that have pressure heads within 10 feet (3.0 m) of ground surface.

Evidence of Upper Cretaceous clay-shales in soil parent materials and low pressure heads in bedrock aquifers suggest that lithogenic processes of sodium accumulation may be dominant. Additional evidence of moderately saline parent materials confined to lower slopes in the local landscape and the fact that sodium accumulation in other solonetzic soils, in portions of the Eyebrow Hills, favoured paleohydromorphic processes suggest that sodium accumulation in Amulet-Brooking solonetzic soils may also be related to paleohydromorphic processes.

Significant Solodic Weyburn-Hanley and Weyburn-Rosemae soils occupy areas in the eastern portion of the Central Butte Plain. Several areas of depressional Saline Regosolic soil occur within Weyburn-Hanley and Weyburn-Rosemae soils. Weyburn-Hanley and Weyburn-Rosemae soils occur on gently sloping to gently and roughly undulating topography. Weyburn parent materials consist of moderately to strong calcareous, nonsaline unsorted glacial till while Hanley parent materials consist of moderately calcareous, saline, silty glacio-lacustrine deposits and Rosemae parent materials consist of moderately to strongly calcareous, saline, unsorted glacial till (Ayers et al., 1985). Weyburn soils occupy knolls and upper slopes while Hanley and Rosemae soils occupy areas between lower slopes and depressions (Ayers et al., 1985). Seven water wells completed in bedrock aquifers have pressure heads near and above ground surface. Positions of the water wells in the local landscape is unknown but it is assumed that they occur in lower depressional areas.

An absence of Upper Cretaceous shales in soil parent materials, moderately to strongly saline parent materials confined in lower slopes, medium to very high sodium salts in waters from bedrock aquifers, several water wells completed in bedrock aquifers with pressure heads near and above ground surface, and several areas of Saline Regosolic soil in local depressional areas suggest that hydromorphic processes of sodium accumulation is dominant in significant Solodic soils in eastern portions of the Central Butte Plain.

Sodium salt accumulation probably occurred at a past time when pressure heads in bedrock aquifers were greater than presently indicated. Desalinization, solonization, and finally solodization probably occurred as a result of falling pressure heads and may represent a stepwise transformation from past Solonetzic profiles to present day Solodic profiles. Sodium salt accumulation in Significant Solodic soils in eastern portions of the Central Butte Plain may be related to paleohydromorphic processes.

CONCLUSIONS AND FUTURE OUTLOOK

Sodium accumulation in the Hanley study area appears to be a combination of hydromorphic and paleohydromorphic processes. Hydrogeologic evidence suggests that hydromorphic processes are dominant at lower elevations between the Hawarden and Allan Hills Uplands while paleohydromorphic processes are dominant at higher elevations in significant Solonetzic and significant Solodic soils in portions of the Hawarden Hills and Allan Hills Uplands.

Sodium accumulation in the Central Butte study area appears to be a combination of hydromorphic, lithogenic and paleohydromorphic processes. Hydrogeologic evidence suggests that lithogenic and hydromorphic processes may occur in dominant Solonetzic soils in the Central Butte Plain. Hydromorphic processes appear strongest in eastern portions of the Central Butte Plain while lithogenic processes may be dominant in western portions of the Central Butte Plain. Several depressional Saline Regsolic areas in western portions of the Central Butte Plain may support hydromorphic and perhaps paleohydromorphic conditions of sodium accumulation.

Hydrogeologic evidence suggests that paleohydromorphic processes are dominant in most dominant Solodic, significant Solonetzic and significant Solodic soils in southern portions of the Central Butte Plain, northern portions of the Missouri Coteau Upland, and portions of the Eyebrow Hills Upland.

By defining pertinent factors that contribute to or have contributed to the accumulation of sodium within the pedon, it is hoped that effective management and/or reclamation schemes can be considered, planned and selected for solonetzic areas offering the highest potential.

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